Economic Analysis of the Impact, Adaptation and Mitigation of Climate Change in the Dominant Cropping System of Indo-Gangatic Plains of India

Synopsis

Submitted for the Registration of the

Degree of Doctor of Philosophy (Ph. D.) in

Commerce

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March 2018

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1.0 Introduction

Economic theory is the study of production, consumption and transfer of wealth. One of the major cruxes of economic theory is concerned with "how to fulfill unlimited wants of human being by scarce resources". To fulfill the unlimited wants of huge population, the major economies started to produce more and more goods. Industrialization started with the use of coal for energy, and turned to various sources such as diesel, electricity, nuclear energy etc. but, the emission of carbon was the only end product in the environment and it is continuously increasing. The atmospheric concentration of carbon dioxide has increased from 280 ppm to 400 ppm (IPCC, 2014; Mina et al., 2017). This increased atmospheric carbon dioxide along with some other gases is causing the global warming and ultimately the changes in the environment and climate.

In the present era of industrialization, though, economies are focusing more on industrial development; the agricultural activities still play a vital role in the development of the underdeveloped and emerging economies. The contribution of agricultural is still significant in total GDP of these economies. A large proportion of population in underdeveloped and emerging economies directly or indirectly depends on agricultural. The food security of huge population all around the world and basis of many agro-based industries makes agricultural one of the most prominent sector for world economies.

Agriculture is the most dominant and diverse land use in India, accounting, on average, for about 16 percent of GDP and 10 percent of export earnings (Kumar and Bhatia, 2012). India's gross irrigated crop area of 82.6 million hectares (215.6 million acres) is the largest in the world (USDA 2011). India has grown to be among the top three global producers of a broad range of crops, including wheat, rice, pulses, cotton, peanuts, fruits, and vegetables. Climate change is one of the key factors

affecting the agro-food production and agricultural practices in India and worldwide; and also poses new challenges to agriculture because of greenhouse gas emission (GHG). It is difficult to reduce GHG emission without directly influencing the volume of agricultural production. In India, farming contributes to 28 percent of the national GHG emission (INCCA, 2007). However, with the help of guidance and technology, e.g. low carbon agriculture it can be reduced.

Agriculture is the source as well as sinks of the carbon dioxide, and is highly affected by the impact of climate change on productivity and livelihood of the farmers. Agricultural soils contribute to the greenhouse effect, primarily through the emission and consumption of GHG, such as methane, nitrous oxide and carbon dioxide. The global warming potential of CH_4 is 25 and of N_2O is 298 over a 100 years' time horizon as compared to CO_2 whose Global-warming potential (GWP) is 1 (IPCC, 2007). GWP is a relative measure of how much heat a GHG traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. Agriculture accounts for 54 percent and 58 percent of global anthropogenic methane and nitrous oxide emissions (Kumar and Bhatia, 2012).

There is a general lack of awareness and information among farmers about causes and risks of climate change. Farmers are puzzled by the worsening rainfall patterns and recurrent drought spells. Given the predicted economic impacts of climate change in the years to come, it is imperative that farmers gain a sound understanding of the causes and impacts of climate change. A fundamental starting point in encouraging the use of low GHG emission agricultural techniques is through information dissemination and capacity-building. This platform is commonly used to address farmers' concerns and to show how communities elsewhere are benefiting from the adoption of various low carbon techniques.

It is also important to realise the importance of creating a platform for exchanging ideas among farmers themselves, given that they are more familiar with their communities. It is worth mentioning that the benefits of low GHG emissions farming are not only for the present generation,

but also for generations to come. The farmers, who are early adopters of new crop technologies, subsequently produce substantial yields in most farming seasons and are ‘successful’. If these farmers begin to use low GHG techniques, other farmers are likely to do the same. The carbon trading is also a motivation to farmers for adopting the low carbon agriculture.

The economic mitigation potential for agriculture in 2030 is estimated to be 70-1260 MtCO2-eq/yr at up to 20 US$/tCO2-eq, and 560-2320 MtCO2-eq/yr at up to 50 US$/tCO2-eq. There are no estimates for the additional potential from top down models at carbon prices up to 100 US$/tCO2-eq, but the estimate for prices above 100 US$/tCO2-eq is 2720 MtCO2-eq/yr. These potentials represent mitigation of 5-80 percent and 20-90 percent of all other agricultural mitigation measures combined, at carbon prices of up to 20, and up to 50 US$/tCO2-eq respectively. An additional mitigation of 770 MtCO2-eq/yr could be achieved by 2030 by improved energy efficiency in agriculture (Smith et al., 2007).

1.1 Climate Change

Climate is the sum of the weather conditions prevailing in an area in general or over a period of time. Climate change is termed as a statistically significant variation in either the mean state of the climate or its variability, persisting for an extended period. The United Nations Framework Convention on Climate Change (UNFCC) defined climate change as a change of climate, which alters the composition of global atmosphere due to human activities directly or indirectly. The alternation of global atmosphere is change in weather pattern, increase in temperature, fall in average annual rainfall, change in timing of precipitation etc.

The excess GHG emission and accumulation in the layers of atmosphere leads to rapid increase the temperature and is also responsible for fall in average annual rainfall. The temperature of earth starts increasing with excess emission of carbon dioxide (CO_2), sulfur dioxide (SO_2) and other pollutants from the factories and other human activities. The earth’s mean annual temperature is increasing year by year. It was 13.74 °C in the year 1900 and it moved to 14°C in the year 1970.

The mean annual temperature of earth was 14.71 in the beginning of 21th century. According to NASA the average temperature of the earth has increased by 0.8° C in last hundred years. Scientists first time started to discuss about climate change in the late of 19th century. Later, due to huge emission of GHG from factories in the start of the 21th century, the whole world started discussing about the increasing temperature of earth.

1.2 Impact of Climate change on Agriculture Crops

Agriculture is an open field economic activity which directly depends on the climatic conditions of the area. Climatic conditions of the area determine the success of agriculture. In developing countries where the huge part of the population depends on the agriculture and it contributes significantly to country's GDP, the agriculture becomes more crucial. The changing scenario of world's climatic conditions has direct impact on agriculture. Modern technology, fertilizers, pests, climate change etc. have impact on crops yield.

Researchers predict positive impacts of climate change on agriculture, like increased temperatures and higher CO_2 levels (Robert et al., 1994). Increased concentrations of CO_2 may boost crop productivity in C_3 crops especially, only where moisture is not a constraint. Higher levels of CO_2 can stimulate photosynthesis in certain plants. Experimental observations confirm that when plants absorb more carbon, grow bigger and more quickly. This is particularly true for some plants which correspond to mid-latitude food staples like wheat, rice and soya bean. Increased CO_2 tends to suppress photo-respiration in these plants, making them more water-efficient.

In case of others which correspond to low-altitude crops like maize, sorghum & sugarcane, the impact on yields is more difficult to predict. The CO_2 fertilization effects would be higher on C_3 crops (such as wheat, rice and soya bean) than on C_4 crops (such as maize, sorghum & sugarcane), because the former is more susceptible to carbon dioxide shortage. Moreover, the protein content of the grain decreases under combined increases of temperature and CO_2 due to the carbon fertilization effect. For rice, the amylase content of the grain, a major determinant of cooking quality

(chalkiness), is increased under elevated CO_2. With wheat, elevated CO_2 reduces the protein content of grain.

1.3 Climate Change and Indian Agriculture

More than half (56 percent) of India's population depends on agriculture. Agriculture is one of the major pillars of Indian economy among the service and industry sector, it contributes around 17.5 percent of country's GDP (World Bank, 2016).

India is home to extraordinary variety of climatic regions, ranging from tropical in the south to temperate and alpine in the Himalayan north, where elevated regions receive sustained winter snowfall. The nation's climate is strongly influenced by the Himalayas and the Thar Desert. Four major climatic groupings predominate into which fall seven climatic zones which are defined on the basis of temperature and precipitation.

The Precipitation plays a very vital role in agricultural activities of any region. The four months of monsoon period define the success of the agriculture activities, that's why the Indian agriculture is called as the "Gamble of monsoon" and this monsoon determine the growth rate of the different countries of the subcontinent. Thus, climatic conditions are directly related with the welfare and development of the countries.

In many Indian regions, 10-15 percent increase in monsoon is precipitated. A simultaneous precipitation decline of 5-25 percent in drought-prone central India and a sharp decline in winter rainfall in northern India are also projected. This implies changes in output of winter wheat and mustard crops in north-western India (Senapati et al., 2013). A decrease in the number of rainy days (5–15 days on average) is expected over much of India, along with an increase in heavy rainfall days and in the frequency of heavy rainfall events in the monsoon season (Kumar et al., 2006). These changes are expected to increase the vulnerability of Indian agriculture. This is particularly important in India, where agriculture is highly sensitive to monsoon variability as 65 percent of the

cropped area is rain-fed (Chang, 1987). Changes in temperature and precipitation could have a significant impact on more than 350 million people who are dependent on rain-fed agriculture.

1.4 Indo-Gangetic Plains (IGP)

Indo-Gangetic Plains (IGP)**,** also called North Indian Plains, is one of the oldest plains situated in extensive north-central section of the Indian sub-continent. It is stretching westward from (and including) the combined delta of the Brahmaputra River Valley and the Ganga River to the Indus River Valley. The greater part of IGP is made up of alluvial soil, deposited by the three main rivers and their streams. The eastern part of the plains has light rains or drought in the winter, but in summer rainfall is so heavy that vast areas become swamps or shallow lakes. The plains become progressively drier toward the west where it incorporates the Thar (Great Indian) Desert.

IGP covers nearly 15 percent of total geographical area of the country and it is extended from 73° East and 32° north to 89° East and 21° North (Koshal, 2014). It includes major states of North India, Punjab, Haryana, Utter Pradesh, Bihar and West Bengal. Nearly 38.4 percent of Indian population lives in these states (Census, 2011). The IGP is a blessed plain of the world, suitable for agricultural activities because of adequate water supply through rivers and seasonal monsoon rainfall. IGP is known for its agricultural productivity due to its traditionally fertile nature. It ensures employment and food security in whole south Asia.

IGP is very crucial from the point of production of major food grain crops. It is known as India's bowl of food grains because it contributes 48.4 percent of rice and 74.7 percent of wheat in total Indian production of these two major food grains crops. Most of the areas of these plains have two crops in a year. In some areas three crops are produce in a year. Wheat, potato and mustered are the major crops of spring (Ravi) season and rice and paddy are grown in autumn (Kharif) season (Koshal, 2014). The plains have facility of adequate water supply in summer season as it has advantage of monsoon rain and rivers systems like Ganga and Yamuna. The IGP is a blessed region where climatic conditions are ideal for human beings also, so, the population of this region has

increased rapidly in late 20th century. The agriculture activities combined with industrialization that took place very rapidly in this region provide employment to huge population. All these factors make this area very crucial.

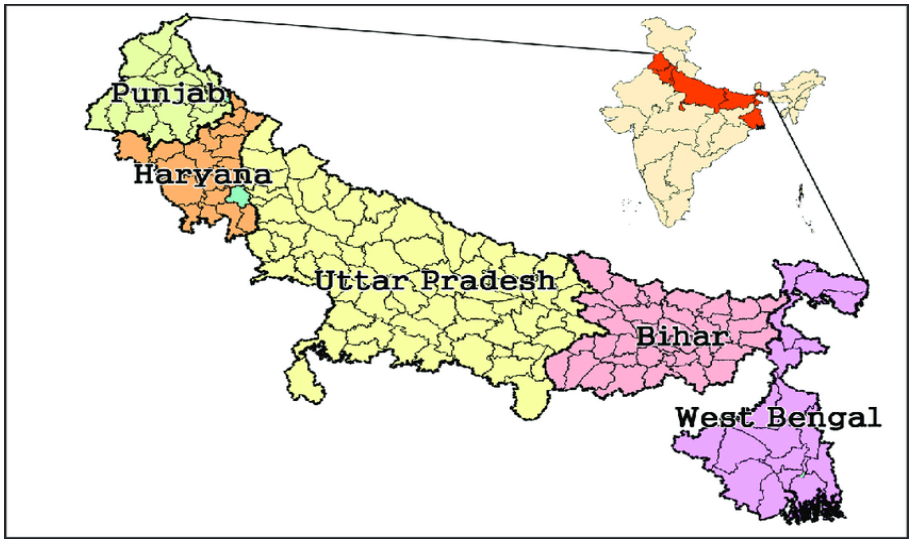

Figure 1: Indo Gangetic Plains Region of India (Source: Google Images)

1.5 Climatic Conditions in IGP

The rapid industrialization, burden of huge population, urbanization, over-exploitation of land and excessive use of pets, fertilizers etc. have affected the climatic conditions of the region adversely. According to IPCC report (2014) the temperature of earth will be increased by 4°C till the end of this century and the changing climatic trends of IGP also support the conclusions of IPCC report. The climatic condition of this region sketches an important picture about the climatic change.

The climatic trends of the IGP show that the temperature of this region is increasing year by year. The average temperature of this region has increased by 0.2° C per decade from the year 1960. The range of possible temperature increase for IGP is 0.6–2.7° C, 0.5–3.1° C and 1.0–5.4° C above the 1070–1999 mean for the 2030s, 2050s and 2090s respectively. In general, temperatures in the monsoon period increase less than in the dry seasons (New et al. 2012). The researches indicate that though, average precipitation of the plains is static, but the timing of precipitation is changing.

1.6 Adaptation and Mitigation in Agriculture

Adaptation is a process of change by which an organism or species better suited to environment. It refers to measures or techniques which can be used to reduced the impact of particular risk, using irrigation, modern farming technology, fertilizers etc. (Report of Adaptation to Climate Change in the Agriculture Sector 2007, European Commission DG AGRI). Adaptation regarding climate change in agriculture sector is the need of time, as climate change is directly affecting the agriculture and it is a way to minimize the adverse economic impact of climate change. Mitigation is the actions to reduce the severity, seriousness, or painfulness of something, it refers to measures that can be taken to reduce the seriousness of the emission of GHG and slow the process of climate change.

2.0 Present State of Knowledge

To develop better understanding of various dimensions of climate change, the researcher thoroughly reviewed of available literature. Among several aspects of the problem, Zhang et al. (2016), Ahlawat & Kaur (2015), Nube et al. (2015), Ahmad et al. (2014), Koshal (2014), Mishra & Sahu (2014), Gupta et al. (2012), Siddiqui et al. (2012) and Sanghi & Mendelsohn (2008) discussed various dimensions of the impact of climate change on agriculture productivity. Majority of them used regression to analysis the data; however, some researchers used panel data analysis technique. Their findings, in general are similar, as almost all of them concluded that the climate change variables (temperature and rainfall) have adverse impact on agriculture crop yield.

In order to cope-up with the adverse effects of climate change on agriculture, several mitigation strategies are developed, but, their usage is not encouraging. Considering the fact a number of researchers made attempts to examine the aspects related with adaptation of climate change mitigation strategies and also their economic feasibility in different economic environments. Some prominent studies on this issue include Asrat & Simane (2018), Georgopolou et al. (2017), Tripathi & Mishra (2017), Belay et al. (2017), Dhanya & Ramachandran (2016), Ali & Erenstein (2016),

Helling et al. (2015), Sima et al. (2015), Singh et al. (2015), Ahmed & Suphachalasai (2014), Swain (2014) and Zou et al. (2013). They examined the level of adaptation, economic feasibility and effectiveness of selected climate change mitigation strategies used in different geographical locations.

Present era of technology is redefining diverse aspects of human life. In the field of agriculture also use of technology is of utmost importance. Use of modern technology in agriculture processes to combat the climate change effects on agriculture yield is commonly termed as climate smart agriculture. Some researchers, Chhetri et al. (2016), and Chettri et al. (2016) studied the facets of climate smart technologies in agriculture and carried out cost-benefit analysis of selected technologies in different geographical locations.

Some other researchers, Raghuvanshi et al. (2017), Tsojon (2017), Kamruzzaman (2015), Enete (2014), Taneja et al. (2014), Mbilinyi et al. (2013), Adebayo et al. (2012), Ayindea et al. (2011), Nelson et al. (2009), Jain (2007), Guiteras (2007), Molua & Lambi (2007) and Mano & Nhemachena (2007) studied aspects related with farmers' awareness about the effects of climate change, climate change mitigation strategies and their perception regarding adaptation of climate change mitigation strategies by using descriptive statistics; their findings differ region to region.

The review of prominent research studies on climate change conducted in India and abroad is presented in Box 1.

BOX – 1: REVIEW OF EXISTING LITERATURE		
(A) Research Studies Conducted Abroad		
S.N.	**Description of Research Work**	
1	Author(s)	Asrat & Simane (2018)
	Title	Farmers' perception of climate change and adaptation strategies in the Dabus watershed, North-west Ethiopia
	Objective(s)	To analyze farmers' perception and adaptation to climate change in Dabus watershed.
	Methodology	The study is based on analysis of data collected from 734 randomly selected farm household heads substantiated with focus group discussions and field observations. The study employed descriptive methods to assess farmers' perception of climate change, local indicators of climate change and types of adaptation measures exercised to cop-up with the risk of the change in climate. It also employed the Heckman sample selection model to analyze the two-step process of adaptation to climate change which initially requires farmers' perception that climate is changing prior to responding to the changes through adaptation measures.
	Findings	The farmers' perception and adaptation measures regarding climate change are governed by location specific factors. The adaptation decisions of farmers are mainly governed by family size, cultivated land size, education level, age and gender of the head of household, number of crop failures in the past, changes in temperature and precipitation, experience of farming, non-farm income, income from livestock, extension advice, farm-home distance climate information, duration of food shortage etc.
2	Author(s)	Georgopolou et al. (2017)
	Title	Climate change impacts and adaptation options for Greek agriculture in 2021-2050: A monetary assessment
	Objective(s)	To present monetary evaluation of the impacts of climate change on major crops and the cost-benefit analysis of adaptation options for selected crops in different regions of Greek.
	Methodology	To address local variability in current and future climate conditions, analysis is spatially disaggregated into geographical regions using as an input downscaled results from climatic models. For some crops, changes in future agricultural yields are assessed by means of agronomic simulation models, while for the rest crops changes are assessed through regression models. The expected effects of potential adaptation options on crop yields are investigated through same models and the costs-benefit analysis of these options is assessed quantitatively.
	Findings	The severity of the impact of climate change on crops yield differs from region to region and crop to crop. Several climate change adaptation measures are economically acceptable in different geographical areas. Further, use of fertilizers, climate-resistant cultivars etc. are good and economically acceptable adaptation measures in different regions under study.

3	Author(s)	Belay et al. (2017)
	Title	Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia
	Objective(s)	To investigate smallholder farmers' perception about climate change, their adaptation strategies practices and the determinants of their adaptation decisions.
	Methodology	The researchers used both primary and secondary information. Primary data was collected from 200 households divided in three categories, viz., highland, midland and lowland. The tools of data analysis included descriptive statistics, t test, chi-square test and a multinomial logit model.
	Findings	The findings of study indicated that 90 percent of farmers have already perceived climate variability, and 85 percent made attempts to adapt using practices like crop diversification, planting date adjustment, soil and water conservation and management, increasing the intensity of input use, integrating crop with livestock, and tree planting. The results of logit model revealed that the key factors determining farmers' choice of adaptation practice included education, family size, gender, age, livestock ownership, farming experience, frequency of contact with extension agents, farm size, access to market, access to climate information and income.
4	Author(s)	Ali & Erenstein (2016)
	Title	Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan
	Objective(s)	To assess the factors influencing the farmer's choice of climate change adaptation practices and associated impacts on household food security and poverty in Pakistan.
	Methodology	The study is based on primary data of 950 farmers collected from 4 major districts of Pakistan. The researchers, with a view to investigate determinants of climate change adaptation practices used probit model; to analyze the determinants of the number of adaptation practices, censored least absolute deviation (CLAD) was used; and to evaluate the impact of adaptation practices on food security and poverty levels, they used propensity score matching (PSM) approach.
	Findings	The researchers observed shifting to new crops, adjustment in sowing time, and use of drought tolerant varieties as three major adaptation practices used by farmers. The findings of the study indicate that younger farmers and farmers with higher levels of education are more likely to use these adaptation practices. The number of adaptation practices used was found to be positively associated with education, male household heads, land size, household size, extension services, access to credit and wealth. Farmers adopting more adaptation practices had higher food security levels than those who did not, and experienced lower levels of poverty.
5	Author(s)	Zhang et al. (2016)

	Title	Economic impacts of climate change on agriculture: The importance of additional climatic variables other than temperature and precipitation
	Objective(s)	To explore additional climatic variables other than temperature and precipitation.
	Methodology	The study used regression analysis on county-level agricultural data for 30 years from 1980 to 2010 in China.
	Findings	The findings of study reveal that the additional climatic variables, especially humidity and wind speed are critical for crop growth. Omitting these variables is likely to bias the predicted impacts of climate change on crop yields. Omitting humidity in particular, tends to over predict the cost of climate change on crop yields, while ignoring wind speed is likely to under predict the effect.
6	Author(s)	Ncube et al. (2015)
	Title	The impact of climate change on agricultural output in South Africa (1997-2012)
	Objective(s)	To investigate the impact of climate change on agriculture output in South Africa.
	Methodology	The study is based on secondary data on temperature, rainfall, labor and capital and the GDP in agricultural sector. To examine the impact of climate change on output, researchers used unit root tests and the ordinary least squares (OLS) method.
	Findings	The study concluded by stating that there is negative relationship between climate change (rainfall & temperature) and agriculture output in South Africa.
7	Author(s)	Helling et al. (2015)
	Title	Economic analysis of climate change best management practices in Vermont agriculture
	Objective(s)	To assess cost of implementing and maintaining climate change specific best management practices for diverse farms in Vermont.
	Methodology	The study is based on three climate change specific best management practices for twelve farms of Vermont, USA, viz., cover cropping, management intensive rotational grazing, and riparian buffer strips.
	Findings	The findings of the study reveals that the cost of best management practices under climate change are under adaptation, and stakeholders, especially government should provide more help to farmers to cope-up with the problem of climate change.
8	Author(s)	Sima et al. (2015)
	Title	A farmer-based analysis of climate change adaptation options of agriculture in the Bărăgan Plain, Romania
	Objective(s)	To assess the impact of climate change on agriculture in Bărăgan Plain, Romania in context of socio-economic and political factors as key steps towards climate adaptation, and to examine future impact of climate change and adaptation measures on agriculture.
	Methodology	The study is based on both secondary and primary data collected through interview. The researchers analyzed the

		changes in the socio-economic and political context of Romania since 1989, the post-communist period, marked by fundamental transformations in agriculture. To estimate the potential climate change impacts on agriculture, they used a set of relevant climate extreme and agro-meteorological indices.
	Findings	The study difference between adaptive capacity of large farms with a high adaptive capacity and low subsistence farms (family-run farms), the most vulnerable category to both socio-economic and climate change. It also observed that farmers of area are aware of climate change; they viewed about the severity of drought and high rainfall. Farmers considered rehabilitation/ construction of irrigation systems as most crucial climate adaptation measure.
9	Author(s)	Ahmed & Suphachalasai (2014)
	Title	Assessing the costs of climate change and adaptation in South Asia
	Objective(s)	To assess the biophysical impacts of climate change, estimate scenario-based/ sector-based economic loss to selected six countries in South Asian region toward the year 2100, and estimate the magnitude of funding required for adaptation measures to avert such potential losses.
	Methodology	The researchers reviewed relevant knowledge and initiatives in South Asia, gathered information from stakeholders, and developed quantitative model of climate change, its impact and adaptation, and economic implications.
	Findings	The findings of the study revealed that the total cost of climate change will increase with time and it will be very high in long run. The assessed cost of climate change is estimated to be 1.5 percent of South Asian countries' GDP by year 2050 and 8 percent by year 2100. India may lose 1.8 percent of total GDP by 2050, while Maldives will have maximum loss. The cost of adaptation is estimated at 0.48 percent of GDP per annum by 2050 and 0.86 percent by 2100. The researchers finally viewed that climate change adaptation is a huge risk management challenge involving many uncertainties. A flexible learning approach to crafting policies for climate adaptation is a good approach when dealing with uncertainty, starting with measures that will not be regretted.
10	Author(s)	Ahmad et al. (2014)
	Title	Impact of climate change on wheat productivity in Pakistan: A district level analysis
	Objective(s)	To study the impact of climate change on productivity of wheat in different districts of Pakistan.
	Methodology	The study is based on secondary data of 19 major wheat producing districts of Pakistan over a period 1981 to 2010. It used production function approach to estimate the impact of climate change on agriculture.
	Findings	The study observed that climate change is significantly affecting wheat productivity in Pakistan and that the impact varies across growth stages of the crop. Further, the increase in long-run mean temperature during germination and tillering stage effects wheat yields adversely, while in vegetative growth stage, increase in mean

		temperature enhances wheat productivity especially in cold regions of the country. The results also indicated that an increase of 1^0C in the mean temperature during germination and tillering stage would reduce crop yield by 7.4 percent and an increase in mean temperature by 1^0C during vegetative growth stage will enhance wheat productivity to the tune of 6.4 percent.
11	Author(s)	Zou et al. (2013)
	Title	Cost-effectiveness analysis of water-saving irrigation technologies based on climate change response: A case study of China
	Objective(s)	To examine the economic feasibility of water-saving irrigation technologies to cope with effects of climate change.
	Methodology	The study conducted cost effectiveness analysis of four water-saving irrigation techniques, viz., sprinkler irrigation, micro-irrigation, low-pressure pipe irrigation and channel lining by using data on investment, annual operation and maintenance, annual average energy saved, annual average water fee and the crop yield.
	Findings	Based on the cost effectiveness analysis, this study observed that water-saving irrigation is cost-effective in coping with climate change. It is beneficial for climate change mitigation, adaptation, and sustainable economic development. The results of analysis indicated that the cost-effectiveness ratio of mitigation and adaptation of all the techniques, except channel lining is positive. The study suggested that for mitigation and adaptation objectives, micro-irrigation performs best, however, from economic perspective, channel lining is considered better.
12	Author(s)	Siddiqui et al. (2012)
	Title	The impact of climate change on major agricultural crops: evidence from Punjab, Pakistan
	Objective(s)	To investigate the impact of climate change on four major crops in Punjab province of Pakistan, and also to makes projections regarding the effects of changes in temperature and precipitation on the crops production.
	Methodology	The study is based on secondary data of 29 years from 1980 to 2009. Researchers used Fixed Effect Model (FEM) considering crop productivity as dependent variable and temperature and precipitations in four stages as explanatory variables. In order to capture the nonlinearity impact, they included squared term for variables under consideration.
	Findings	The findings of the study reveal that in the short run the increase in temperature is expected to have negative effect, while in long run it is expected to have positive effects on wheat productivity. Similarly, the increase in precipitation has negative impact in both short and long term. Though, rise in temperature is beneficial for rice production initially, but beyond a certain optimal temperature, increase in temperature becomes harmful for rice production. Interestingly, the increase in precipitation does not harm the rice productivity. Further, the change in

		temperature and precipitation has a significant negative impact on production of cotton and the increase in temperature also harms the sugarcane productivity in long term.
13	Author(s)	Sanghi & Mendelsohn (2008)
	Title	The impacts of global warming on farmers in Brazil and India
	Objective(s)	To examine the impacts of climate variability on net farm values of farmers of India and Brazil and how the farmers in India and Brazil react and adapt to climate.
	Methodology	The study is based on secondary data of 3491 municipios of Brazil and 271 districts of 13 states from India. To estimate the climate sensitivity of agriculture in Brazil and India researchers employed cross-sectional analysis. Using panel data from both countries, the study measured how net farm income or property values vary with climate, and consequently, how farmers in India and Brazil react and adapt to climate. The estimated relationships are then used to predict the consequence of alternative climate scenarios.
	Findings	The findings of the study revealed that global warming by the end of the next century could cause annual damages in Brazil between 1% and 39% and between 4% and 26% in India, although some of this effect may be potentially offset by carbon fertilization. Further, the researchers observed that a rise in temperatures by 2^0C with an 8% increase in precipitation, agricultural net revenue may fall 12% in India and 20% in Brazil without carbon fertilization. Based on broader range of possible climates, the range of annual damages varies between 4% and 26% for India and between 1% and 39% for Brazil.
(B) Research Studies Conducted in India		
S.N.	**Description of Research Work**	
1	Author(s)	Tripathi & Mishra (2017)
	Title	Knowledge and passive adaptation to climate change: An example from Indian farmers
	Objective(s)	To study the farmers' perception about climate change, climate risks and adaptation towards climate change.
	Methodology	The study is based on secondary as well as primary information collected through field survey conducted on 45 farmers of three villages (Sariyawa, Gauhaniya, and Kinauli) situated in Faizabad, district, eastern Uttar Pradesh, India. The researchers compared findings of primary data extracted by using content analysis with climatic and agriculture information collected from secondary sources.
	Findings	The findings of the study indicate that though farmers are aware of long-term changes in climatic factors, e.g., temperature and rainfall, and also of risks generated by climate variability and extreme climatic events, they are unable to identify these changes as climate change. Though, farmers are changing their agricultural and farming practices, they are not taking concrete steps in dealing with perceived climatic changes. These include changing sowing and harvesting timing, cultivation of crops of short duration varieties, inter-cropping, changing cropping

		pattern, investment in irrigation, and agro-forestry.
2	Author(s)	Chhetri et al. (2016)
	Title	Economic benefits of climate-smart agricultural practices to smallholder farmers in the Indo-Gangetic Plains of India.
	Objective(s)	To demonstrate potential economic benefits of climate smart agriculture (CSA) practices of smallholders farmers in Indo-Gangetic Plains of India.
	Methodology	The study is based on primary data on households' socio-economic characteristics, crops and cropping practices, climate change risks in agriculture, and adaptation and mitigation strategies collected from 1267 farmers of 2 districts; Vaishali (Bihar) and Karnal (Haryana). The tools of analysis used included estimation of the cost of adoption, change in yields and income for implementation of three major CSA practices in rice–wheat system, and also the multiple regression.
	Findings	The findings of the study indicate that the most of the farmers have achieved a greater yield by implementing CSA techniques. It also unveiled that farmers can increase annual net return of INR 15,712 per hectare with improved crop varieties, INR 8,119 with laser leveling per hectare and INR 6,951 per hectare with zero tillage in rice–wheat system which will help farmers in increasing net agriculture revenue. The econometric analysis indicated that implementations of CSA practices and technologies in smallholder farms in the IGP of India have significant impact on change in total production costs and yield in rice-wheat system.
3	Author(s)	Chhetri et al. (2016)
	Title	Farmers' prioritization of climate-smart agriculture technologies.
	Objective(s)	To assess the farmers' preferences towards climate smart agriculture (CSA) practices as adaptation measure of climate change.
	Methodology	This study applied a participatory assessment method to assess farmers' preferences and willingness-to-pay for selected CSA practices and technologies in diverse rainfall or location specific zones. It considered respondents of 16 villages of 4 districts of Rajasthan state of India further the study used willingness to pay model to examine farmers' preferences towards climate smart agriculture and technologies. The researchers used chi-square test and multinomial ordered probit model to analyze collected information.
	Findings	The study observed that farmers' preferences for 21 selected CSA technologies are marked by some commonalities as well as differences according to their socio-economic characteristics and rainfall zones. The most preferred technologies by local farmers were crop insurance, weather-based crop agro-advisories, rainwater harvesting, site-specific integrated nutrient management, contingent crop planning and laser land leveling. It also observed that farmers' preferences and willingness-to-pay are influenced by technologies and their cost of

		implementation. The results indicated potential for using a participatory CSA prioritization approach to provide information on climate change adaptation planning at local level.
4	Author(s)	Dhanya & Ramachandran (2016)
	Title	Farmers' perceptions of climate change and the proposed agriculture adaptation strategies in a semi arid region of South India
	Objective(s)	To understand farmers' perception regarding climate change and adaptation strategies, and also to examine the impact of their understanding on cropping pattern.
	Methodology	The study primarily used primary data collected through focus group discussions (FGD) with 86 farmers of Kancheepuram district of Tamil Nadu, South India. The researchers analyzed collected data by using basic descriptive statistics.
	Findings	The findings of the study confirmed that majority of the farmers were aware about climate variability and change. Their perceptions and the information gathered, except for rainfall was in accordance with the analyzed observed trends of climate data of the area under consideration. Study also indicated that farmers of the area have their specific adaptation needs, a number of which could be incorporated into site specific adaption strategies and policies.
5	Author(s)	Ahlawat & Kaur (2015)
	Title	Climate change and food production in North-West India
	Objective(s)	To study effects of temperature and rainfall on production of wheat and rice in northwest region of India.
	Methodology	The study focuses on four states of northwest India, viz., Punjab, Haryana, Himachal Pradesh and Jammu & Kashmir. The data on variables under consideration is analyzed by using trend analysis and correlation coefficient.
	Findings	The results revealed that though climatic factors have affected production of wheat and rice in northwest India, other techno-socio-economic factors, along with prevailing agricultural practices are more responsible for decline in crop yields. These factors have mainly arisen due to the negative impact of excessive use of green revolution technology in this region.
6	Author(s)	Singh et al. (2015)
	Title	Assessing economic impacts of climate change and adaptation in Indo-Gangetic Basin
	Objective(s)	To make integrated assessment of climate change and adaptation strategy for rice-wheat growing farms of Meerut district (India).
	Methodology	The study used integrated climate-crop economic modeling framework to access the impact of climate change on crop yields of rice, wheat and per capital income of farmers.

	Findings	The findings of study show the likely impact of climate change on agricultural production systems, and the ways to reduce climate change vulnerabilities through adaptation strategies. The results of sensitivity analysis indicate that under current production system, rice mean yield declined by 8–23 percent while wheat yield declines by 17-29 percent under five climate scenarios. Though decline in mean net farm returns and per capita income was found to be small, a large proportion of farm population (53-79 percent) remained vulnerable to climate change. The assessment of future agricultural systems by 2050s indicated that though the mean net farm returns and per capita income decline by 3–9 percent and 2–6 percent respectively. The adaptation strategy for existing farming system indicated positive impacts on crop yield, farm returns and per capita income.
7	Author(s)	Mishra & Sahu (2014)
	Title	Economic impact of climate change on agriculture sector of Coastal Odisha
	Objective(s)	To explore the economic impact of climate change on agriculture of the coastal zone of Odisha state.
	Methodology	The study considered annual data of nine coastal districts for 10 years (1993-2009) for dependent and control variables. For independent seasonal climate variables, it considered averages over 30 year (1979-2009) climate data. The tools of analysis used include Ricardian approach to measure the impact of climate change on net agriculture revenue, and pooled cross sectional and time series regression to estimate functional relationship between farm level net-revenue and climate variables viz., temperature and rainfall.
	Findings	The findings of the study indicate that there is overall increase in temperature in all the seasons in the area under consideration. The rising temperature might have adverse impact on agriculture health. Further the results reveals that the decreasing rainfall of January season might have negative impact on net revenue, which calls for a greater investment in irrigation in this period. The rainfall in July is beneficial to farming activity in Odisha, however, the increasing trends of temperature for all the seasons might have adverse impact on the health of agriculture sector of coastal Odisha.
8	Author(s)	Koshal (2014)
	Title	Changing current scenario of rice-wheat system in Indo-Gangetic plains region of India
	Objective(s)	To analyze the rice-wheat yield under the changing climatic situations in the Indo-Gangetic plains (IGP) region of India.
	Methodology	The study is based on secondary data of rice-wheat crop yields of five states of IGP. The collected data is analyzed by using trend analysis, correlation and coefficient of variation.
	Findings	Their results of statistical and remote sensing data analysis indicate good correlation between rainfall and rice yield but not with wheat yield. The current scenario of climate changes i.e., global warming, rising of temperature, irregular pattern of rainfall, excess use of fertilizers and irregular pattern of irrigation decline fertility

		of lands. Further, the remote sensing and GIS technology play an important role to control and management of problematic areas.
9	Author(s)	Swain (2014)
	Title	Crop insurance for adaptation to climate change in India
	Objective(s)	To assess the performance of the National Agricultural Insurance Scheme (NAIS), and area based crop yield insurance scheme and the pilot Weather Based Crop Insurance Scheme (WBCIS), an area based rainfall insurance under implementation in the state of Odisha.
	Methodology	The study made use of secondary time series data on performance of the insurance schemes and also the primary information gathered through focused group discussion with insurance users.
	Findings	The study observed that that WBCIS performed better than NAIS because of higher coverage, larger percentage of farmers benefitted, lower premium, faster and more frequent compensation payment and more transparency. But WBCIS covers only weather related risk and the sum assured and its compensation amount are lower. It suggested that instead of having two schemes, a hybrid product combining the advantages of both the schemes should be offered.
10	Author(s)	Gupta et al. (2012)
	Title	Impact of climate change on the Indian economy: Evidence from food grain yields
	Objective(s)	To estimate the impact of climate change on foodgrain yields in India.
	Methodology	The study used panel dataset for physical yield i.e., output per hectare of rice, pearl millets and sorghum in gross cropped area for the period from1966 to 1999. For rice, it considered data of 102 districts of top 9 rice producing states, for pearl millets, it chose 69 districts were chosen amongst the top 9 pearl-millet producing states and in case of sorghum it considered 58 districts amongst the top 7 sorghum producing states of India. The collected data is analyzed by using OLS.
	Findings	The study observed significant positive impact of rainfall and negative impact temperature on rice yield. Further, in case of rice and millets, the former is the leading foodgrain in terms of output and area sown, while the latter is a hardy crop that can withstand the vicissitudes of weather. For rice the evidence is overwhelmingly that both rainfall and temperature matter. But so do other inputs viz. labor, fertilizer and irrigation. For millets, rainfall is the sole determinant (that is statistically significant).

3.0 The Problem

Climate change is the most important global environmental challenge facing humanity with implications for natural ecosystems, agriculture & health (Parikh & Parikh, 2002). The perusal of General Circulation Models (GCMs) on climate change indicate that rising levels of GHG are likely to increase the global average surface temperature by 1.5 to 4.5°C over the next hundred years. The IPCC report (2014) concluded that climate of world is changing and temperature of the world may increase by 2°C to 4.5°C by the end of this century. The difference of average temperature between the last ice age and present climate is 6°C. This will raise sea levels, shift climate zones pole ward, decrease soil moisture and storms.

Agriculture, the main source of income for rural Indians and an important source of country's GDP, is an open field activity directly related with weather patterns and climate. It is most vulnerable regarding climate change. IGP is the most vital area from agriculture point of view. It is known for its suitable climatic conditions and well known bowl of food grains in terms of quantity and quality of crop yield. The average temperature in IGP has increased by 0.2 °C per decade from the year 1960. The increase in temperatures during monsoon period is less than in the dry seasons in IGP. In general, temperature in this region is vulnerable (New et al. 2012). The researches indicate that though, average precipitation of the region is static but the timing of precipitation is changing.

4.0 Research Motivation

The researchers, in the past have examined various dimensions of climate change, such as farmers' awareness about impact and mitigation strategies of climate change, impact of climate change on agriculture yield and socioeconomic status of rural people, but majority of them focused on the developed or underdeveloped countries. Though, a few researchers tried to study one or two aspects of the problem in developing countries, but, their findings were ambiguous, perhaps due to constricted area or inadequate sample size. So far as the knowledge of researcher is concerned, till now, there is no comprehensive study on climate change in reference to IGP of

India. Considering economic importance of IGP of India, researcher has identified some pertinent issues which need to be addressed during the course of study. These are:

1. What are various facets, causes and patterns of climate change in IGP of India?
2. How and in what manner climate change affected agriculture yield, cost of agriculture and the cost of mitigating the effects of climate change in IGP of India?
3. What strategies the Government of India and respective states of the IGP have evolved so far to tackle this problem and to what extent the national and state governments could check the menace of climate change in IGP of India?
4. What is the level of understanding about causes, effects, adaptation and mitigation strategies of climate change among farmers in selected districts of IGP of India?
5. Whether farmers of IGP of India are willing/ ready to change the traditional farming practices by adopting new strategies for climate change adaptation and mitigating strategies?
6. If not/ yes, what is the way forward to tackle this problem in IGP of India?

5.0 Research Objectives

To answer above questions in precise and scientific manner, the objectives of proposed research work are as follows.

1. To analyze economic impact of climate change on dominant cropping system in Indo-Gangetic Plains (IGP) of India.
2. To examine Farmers' awareness and perceptions about causes, effects, adaptation and mitigation strategies of climate change in IGP of India.
3. To carry-out cost-benefit analysis of identified climate-smart agricultural practices for dominant cropping system in IGP of India.
4. To examine efficiency of existing government policies to combat the effects of climate change and suggest ameliorative measures to enhance the resilience of agriculture in IGP of India.

6.0 Research Methodology

6.1 Research Information

- **Dominant Crops:** The dominant crops in IGP of India primarily include wheat and rice.
- **Variables to be considered:** Temperature, Rainfall, Agriculture Yield (Tonnes/ Hectare), Quality of agriculture output, Cost of agriculture operations, Cost of innovative methods, such as, agriculture technology, irrigation methods, fertilizers, insecticides and pesticides. The researcher may consider more relevant variables during the course of study.
- **Information Type:** Both Primary and Secondary Information.
- **Secondary Information:** Secondary information on variables under consideration will be collected for all five states of IGP of India for a from 1996 to 2017. The sources of secondary information will include statistical data base of Indian Statistical Institute (ISI), India Environment Portal (IEP), Department of Agriculture Cooperation – India (DACNET), Open Government Data (OGD) portal of India and State Governments, Food and Agriculture Organization Corporate Statistical Database (FAOSTATE), Department of Agriculture Research and Education (DARE) and Consultative Group for International Agricultural Research (CGIAR). Researcher will also explore information available research papers, working papers, reports of government and other organizations, books, newspapers etc.
- **Primary Information:** Uttar Pradesh, the largest state of IGP region is divided in four zones, viz. East, West, Central and Bundelkhand (Uttar Pradesh Development Report, Planning Commission of India, 2014). The basic statistics of the districts in each zone of Uttar Pradesh collected from database of the Open Government Data (OGD) portal of Uttar Pradesh and the Department of Agriculture Research and Education (DARE) indicate that West Uttar Pradesh is the largest one in terms of area as well as agriculture yield; it covers 27 major Wheat - Rice producing districts.

  Primary information on farmers' awareness and perceptions about causes, effects, adaptation, and mitigation strategies of climate change will be collected through self-

structured exhaustive questionnaire/ information schedule, which will be executed to selected farmers in the sample. The Sample will be drawn from five major wheat-rice producing districts of West Uttar Pradesh. These districts are - Bulandshahar, Agra, Meerut, Etawah and Hapur (based on yield: Tonnes per hectare). For deciding sample size, researcher considered methodology given by Cocharn (1977)[1] and Taro Yamane (1967)[2]. The sample size calculated by Cocharn's equation is 384 and by Yamane's method it comes 400. Accordingly, the researcher decided sample size of 400 respondents to be collected proportionally from the population of farmers in selected districts (see Box 2). The respondents will be selected on random basis.

6.2 Tools of Information Analysis

The secondary information will be analyzed by using basic descriptives, regression analysis, cost-benefit ratio and InfoRCT model. The tools for primary information analysis will include basic descriptives, content analysis and student t-test. The specific research methodology sketched out to accomplish proposed objectives of study is presented in Box 3.

7.0 Proposed Chapter Plan

Chapter 1: Background: An Assessment of Problem

Chapter 2: Theoretical Foundation and Review of Literature

Chapter 3: Climate Change Impact on Dominant Cropping System of IGP of India

Chapter 4: Farmers' View on Climate Change in IGP of India

Chapter 5: Cost–Benefit Analysis of Climate Smart Agriculture Practices in IGP of India

Chapter 6: Evaluation of National and State Policy Framework for Climate Change

Chapter 7: Potential Strategic Solutions for Climate Change in IGP of India

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[1] Cocharn's equation ($n_o = Z^2.p.q/ e^2$) for calculating representative sample from a large population allows desired level of precision (e=0.05), confidence level (0.95), and the estimated proportion of attribute present in the population. Researcher assumes independence of attributes.

[2] Yamane's equation ($n = N/ (1+N (e)^2$) of sample size considers population size and the margin error at desired confidence level.

Chapter 8: Conclusion

BOX – 2: SAMPLE DISTRIBUTION					
S.No.	**District**	**Number of Blocks**	**Number of Villages**	**No. of Cultivators***	**No of Respondents**
1	Bulandshahar	16	1246	2,92,901	107
2	Agra	15	636	2,85,471	103
3	Meerut	17	662	2,70,888	98
4	Etawah	15	2335	1,70,828	62
5	Hapur	4	352	80,836	30
	Total	**70**	**6319**	**11,00,924**	**400**
***** Census-2011, (Compiled), www.censusindia.gov.in. Cultivators in West UP: 53, 75,301.					

BOX – 3: OBJECTIVE SPECIFIC RESEARCH METHODOLOGY	
Objective	**Research Methodology**
To analyze economic impact of climate change on dominant cropping system in Indo-Gangetic Plains (IGP) of India.	The impact of climate change on dominant cropping system in Indo-Gangetic Plains (IGP) of India will be traced by using regression analysis on secondary data of 22 years from 1996 to 2017.
To examine Farmers' awareness and perceptions about causes, effects, adaptation and mitigation strategies of climate change in IGP of India.	The information will be collected by executing self-designed questionnaire to 400 respondents covering various facets of problem under study. The collected information will be analyzed by using basic descriptive and Student t-test.
To carry-out cost-benefit analysis of identified climate-smart agricultural practices for dominant cropping system in IGP of India.	The cost-benefit analysis of climate-smart agricultural practices will be performed by using primary as well as secondary data on indentified climate-smart agricultural practices. The compiled information will be analyzed by calculating cost-benefit ratios of each identified climate-smart agricultural practice.
To examine efficiency of existing government policies to combat the effects of climate change and suggest ameliorative measures to enhance resilience of agriculture in IGP of India.	The existing government policies to combat the effects of climate change will be examined by using primary as well as secondary data. The collected information will be analyzed by using Content analysis and Student t-test.

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